

3-D Vegetation Mapping of Mangrove Forests



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Objectives

Development, analysis and calibration of mangrove height and biomass maps

- ❖ Develop a landcover map of mangrove forests for all of Africa from Landsat ETM+ data.
- ❖ Derive site-specific height calibration equations (and error estimates) for the SRTM DEM from GLAS over mangrove forests.
- ❖ Extrapolate height estimates to mangrove areas not covered by GLAS and produce a 3-D SRTM mangrove height map.
- ❖ Apply global biomass equations to produce mangrove biomass maps and estimates for the African continent.

Relevance

- ❖ Quantifying structure and biomass of forest ecosystems crucial for:
 - ❖ Estimates of Carbon storage, carbon cycle studies and studies climate change
 - ❖ Estimates of Deforestation, reforestation and changes in forest quality
 - ❖ Biodiversity
 - ❖ Conservation
 - ❖ Habitat suitability
- ❖ Vegetation structure describes the size and distribution of vegetation material within a landscape.
- ❖ Individual trees in term of their species, trunk size (DBH) and height.

Mangrove Ecosystems

- ❖ Most common ecosystem in tropical and subtropical coastal areas
- ❖ Biodiversity harbor:
 - ❖ Habitat for over 1300 species of animals
 - ❖ Nursery for fish and crustaceans
- ❖ Among the most productive ecosystems on earth
 - ❖ 2.5g C m^{-2} per day
 - ❖ 25% accumulates in mangrove sediments
 - ❖ 25% recycled
 - ❖ 50% exported to oceans → 10% Global DOC

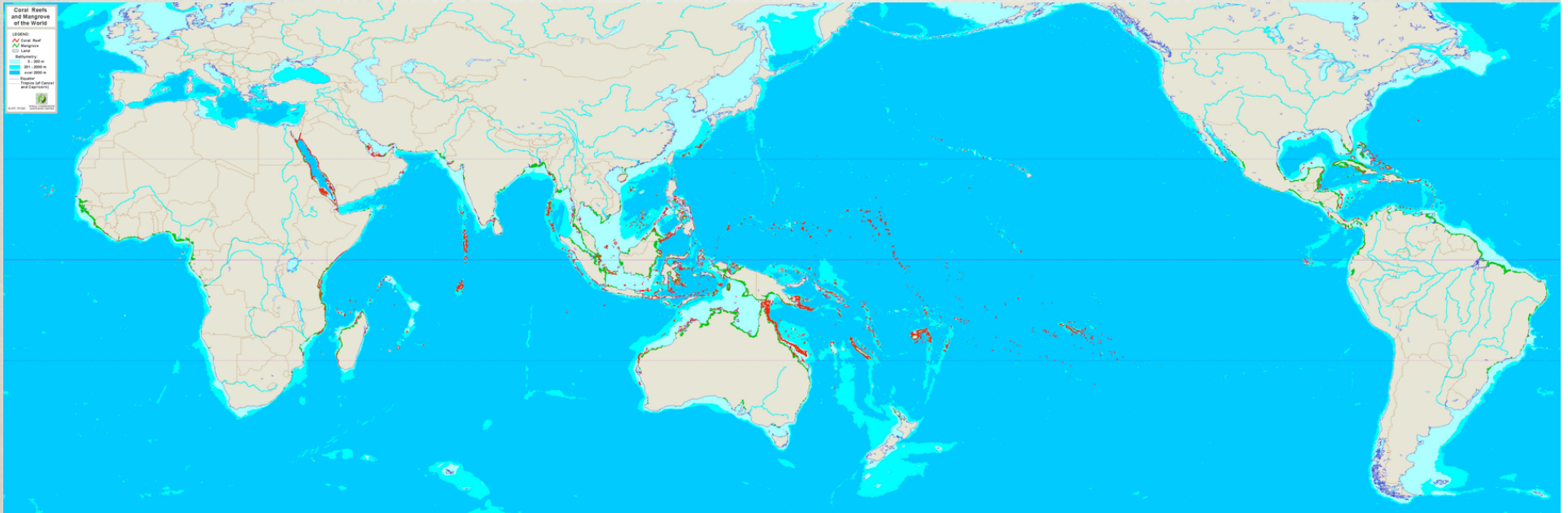


- ❖ Endangered by development, aquaculture and sea-level rise
- ❖ Between 35 % and 50 % of global cover lost in past 60 ye



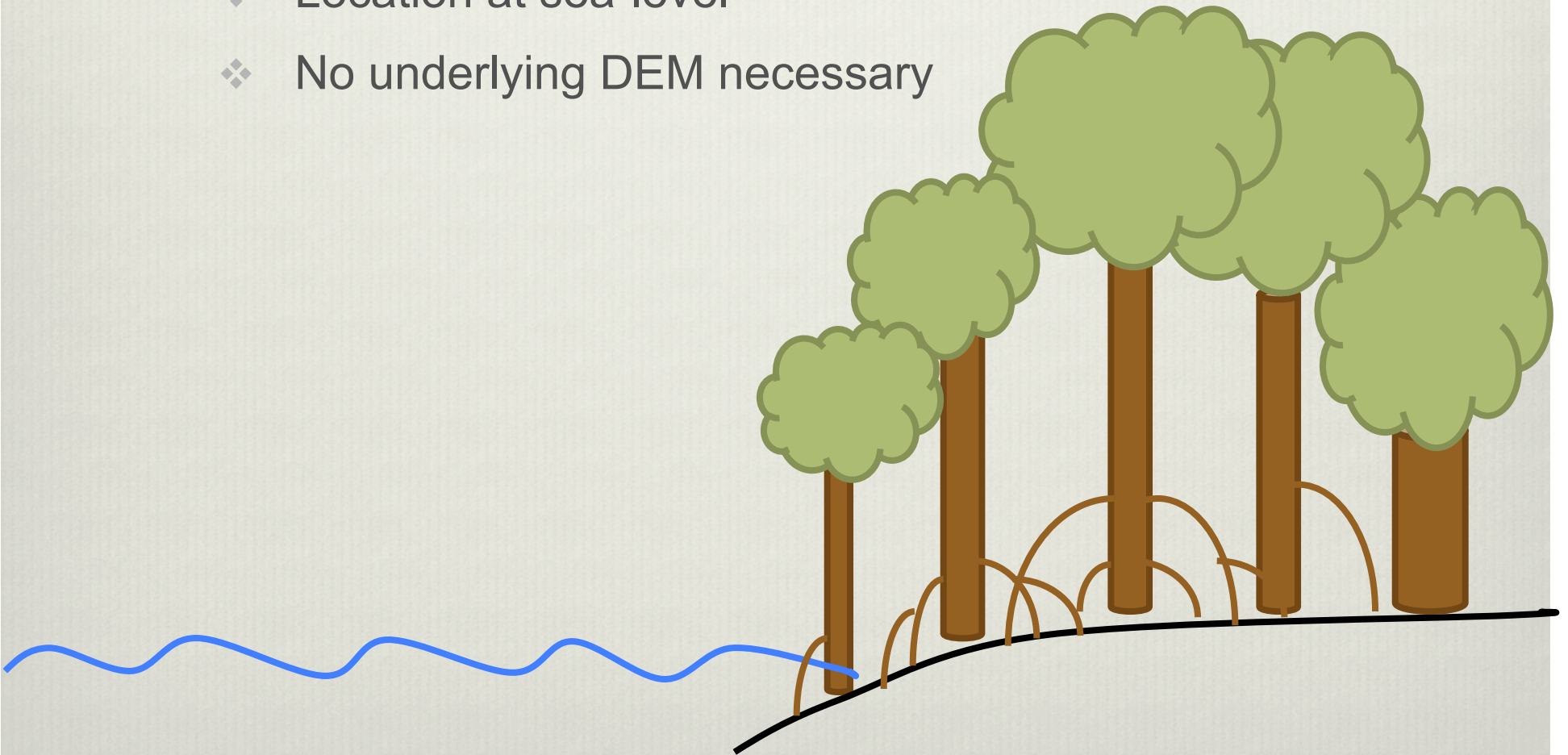
Distribution

- ❖ Globally between the 20 °C winter isotherm
 - ❖ 30 °N and 30 °S
- ❖ Biomass and diversity increase with decreasing latitude
- ❖ In Africa from Mauritania to Angola and from Egypt to South Africa



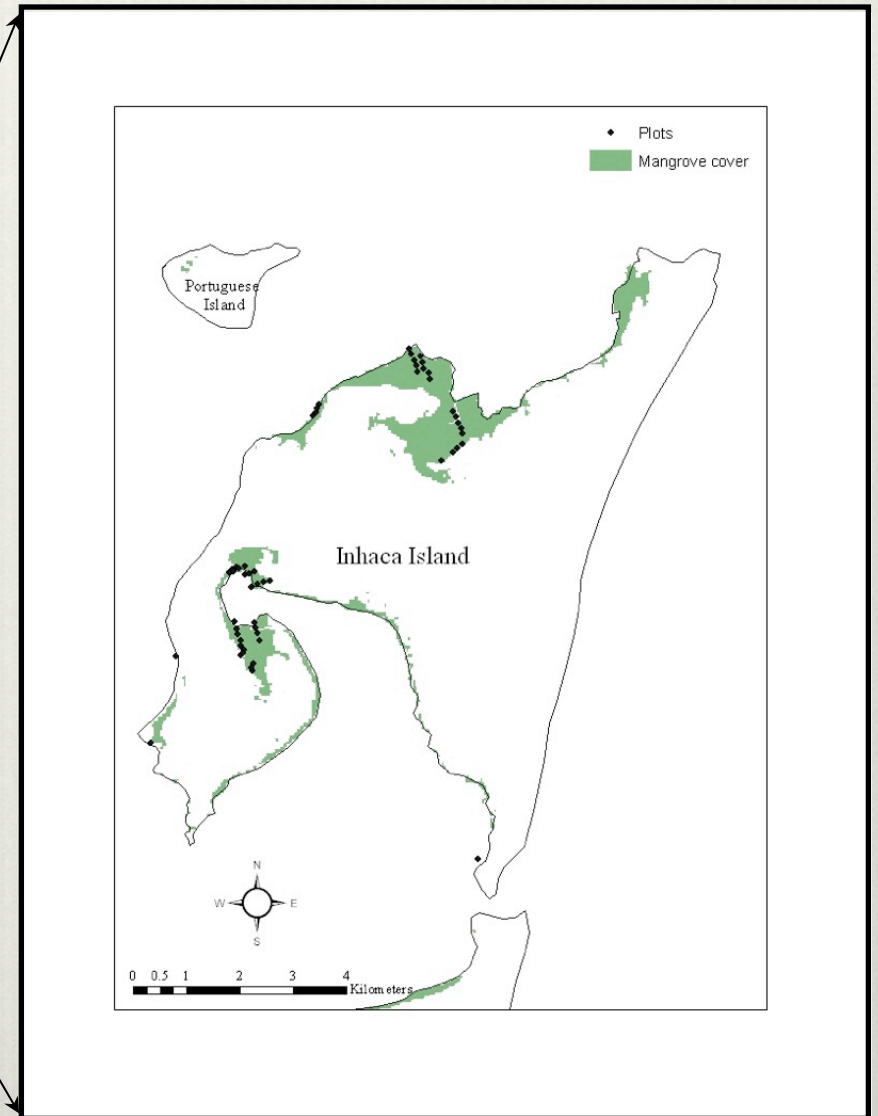
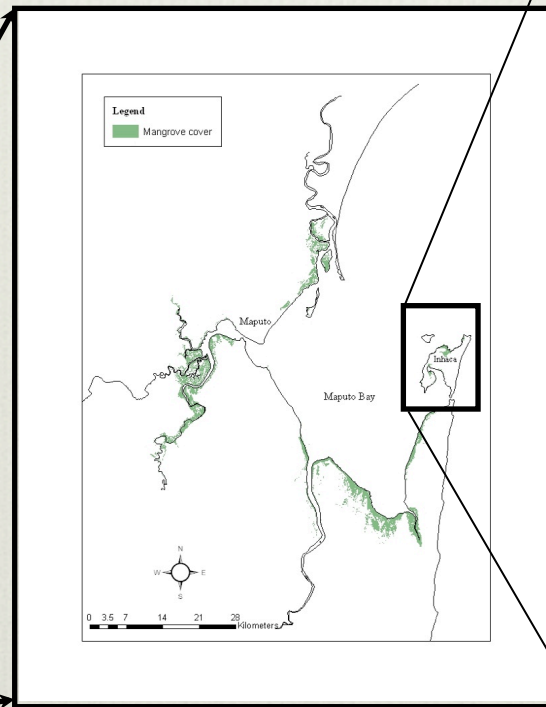
Mangroves as test ecosystem

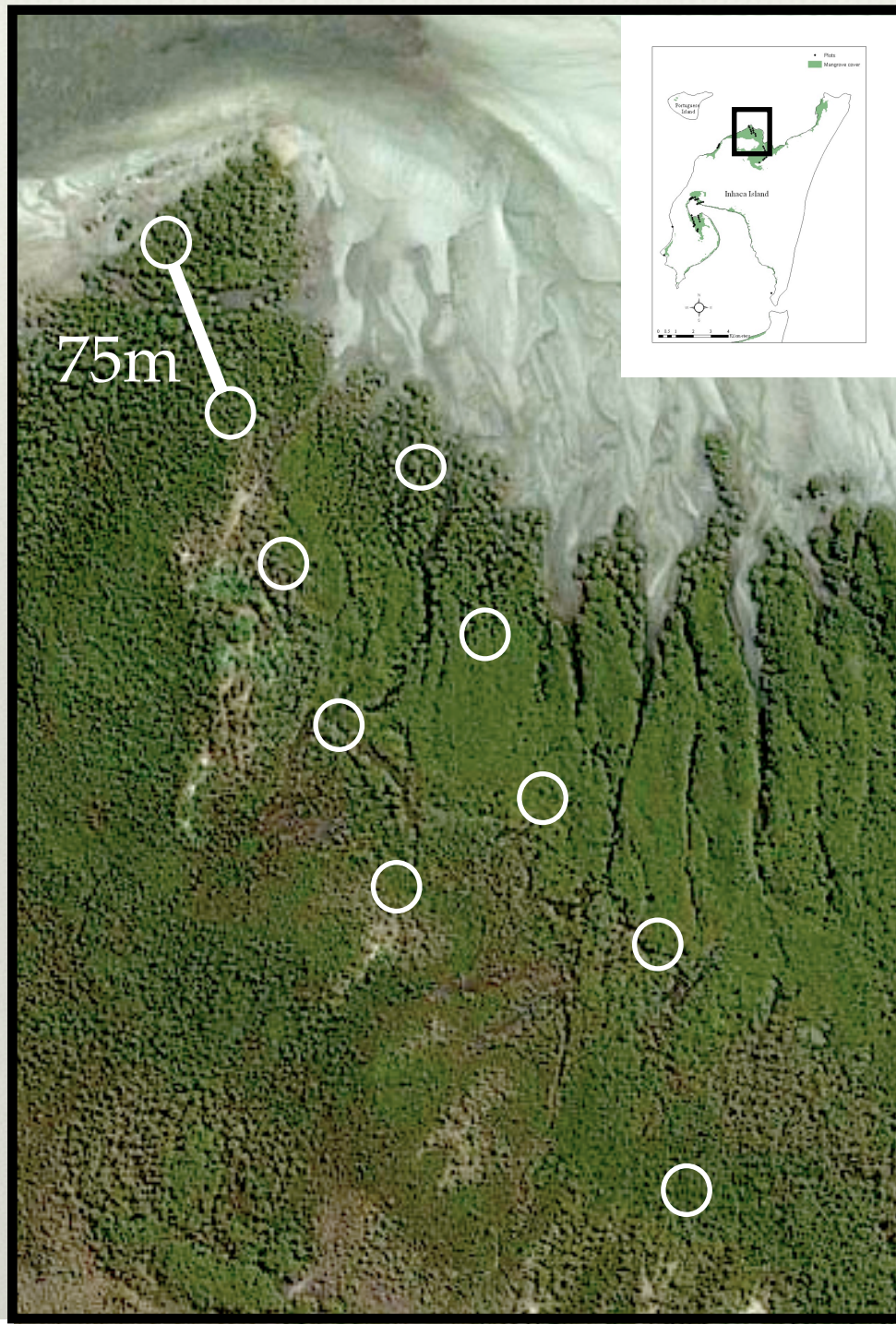
- ❖ Flat topography:
 - ❖ Location at sea-level
 - ❖ No underlying DEM necessary



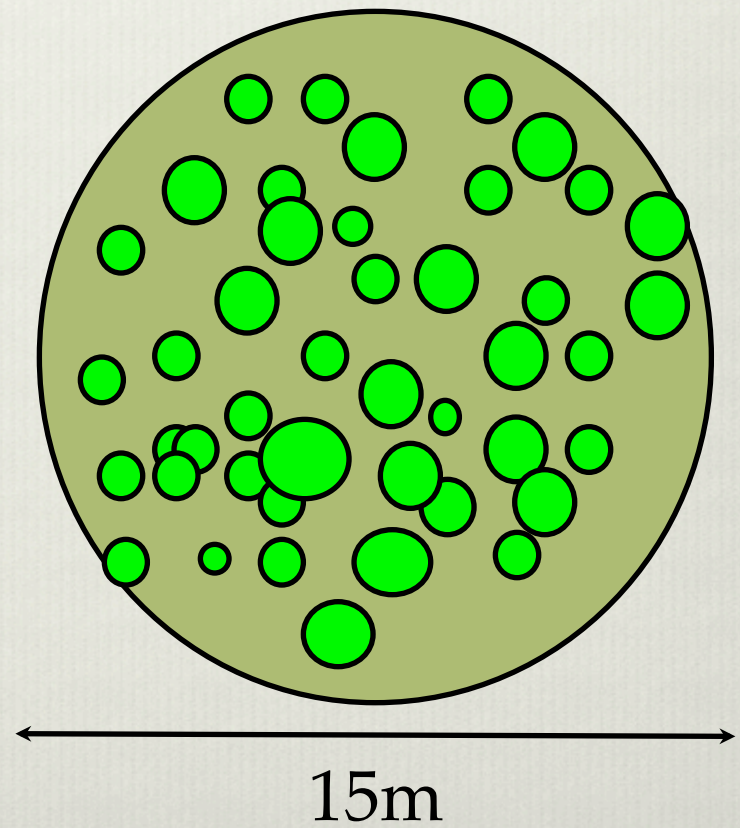
Preliminary Work

Field Work



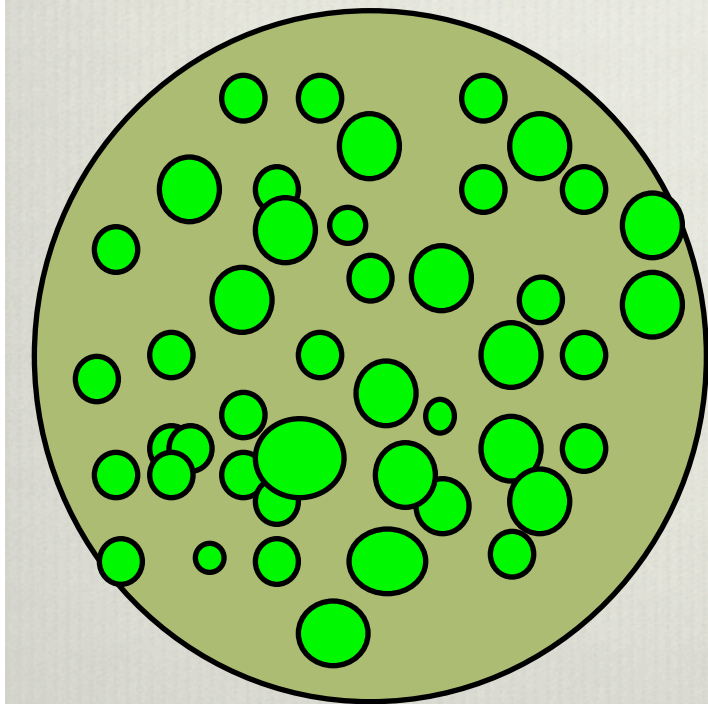


- ❖ 8 transects, 51 plots
- ❖ Forest structure and composition



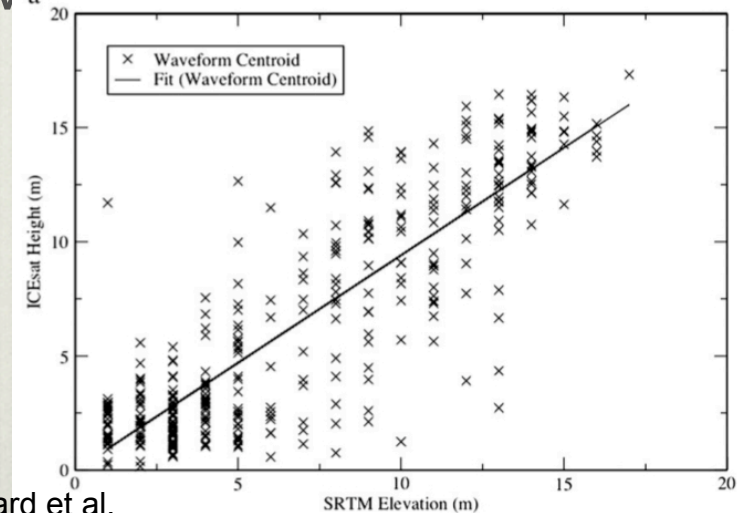
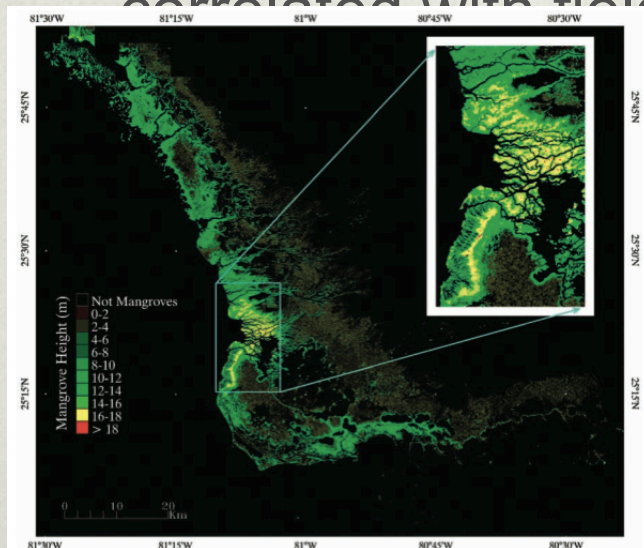
3 Zones: Fringe, Basin, Scrub





Results: Field Work

- ❖ Based on Mozambique height and biomass measurements SRTM height measurements are good indicator of field height (1.6m RMSE) and biomass
- ❖ Based on previous results from Columbia, Florida Everglades, Venezuela, GLAS data is highly correlated with field and SRTM data

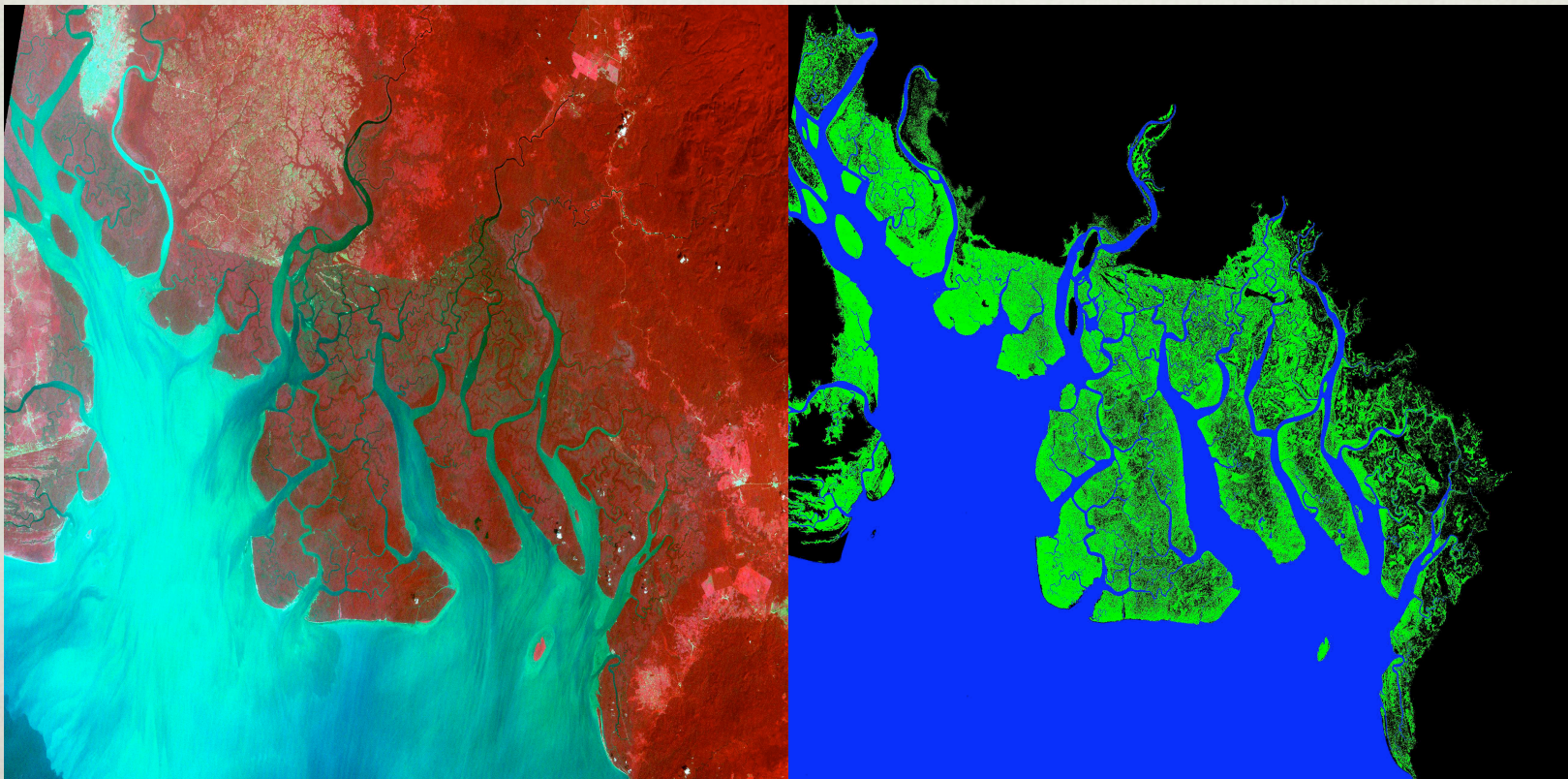


Simard et al,
2008

Methods

Landsat ETM+

- ❖ Landsat ETM+ data good for estimating mangrove cover

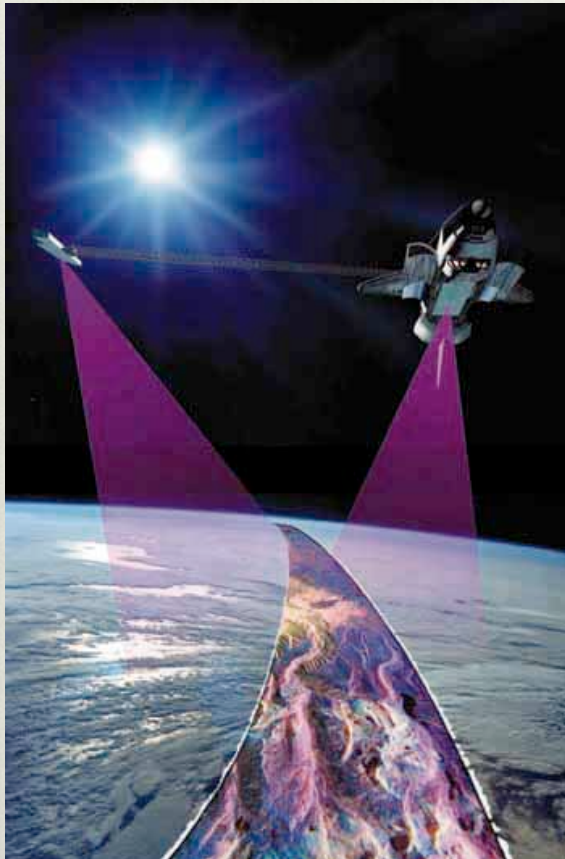


Classification

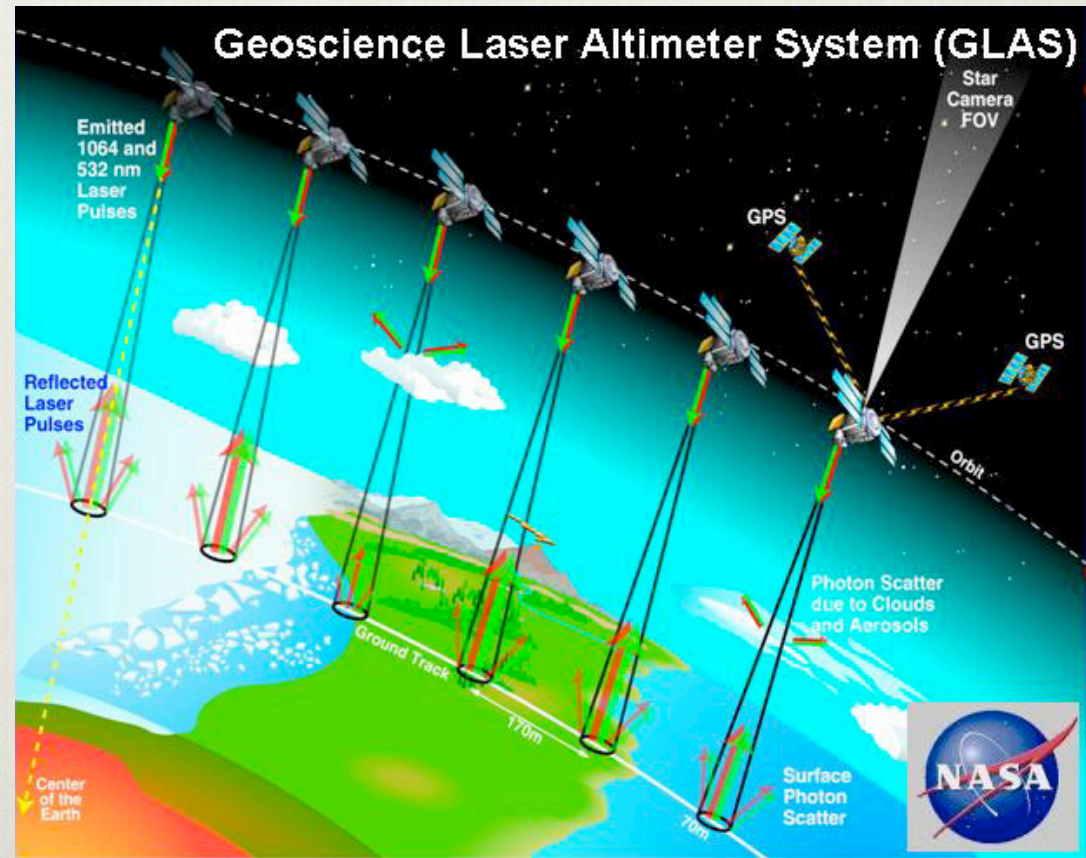
- ❖ Applied ISODATA classification to 117 scenes covering all mangrove areas in Africa
- ❖ Excluded all areas over 40m based on SRTM DEM
- ❖ Mosaic of all scenes to cover the continent
- ❖ Individual country maps:
 - ❖ Facilitation of access for governments
 - ❖ Comparison with previous estimates
- ❖ Error estimation: systematic comparison of mangrove cover to Google earth images every 4 degrees lat/long

Radar & Lidar

SRTM

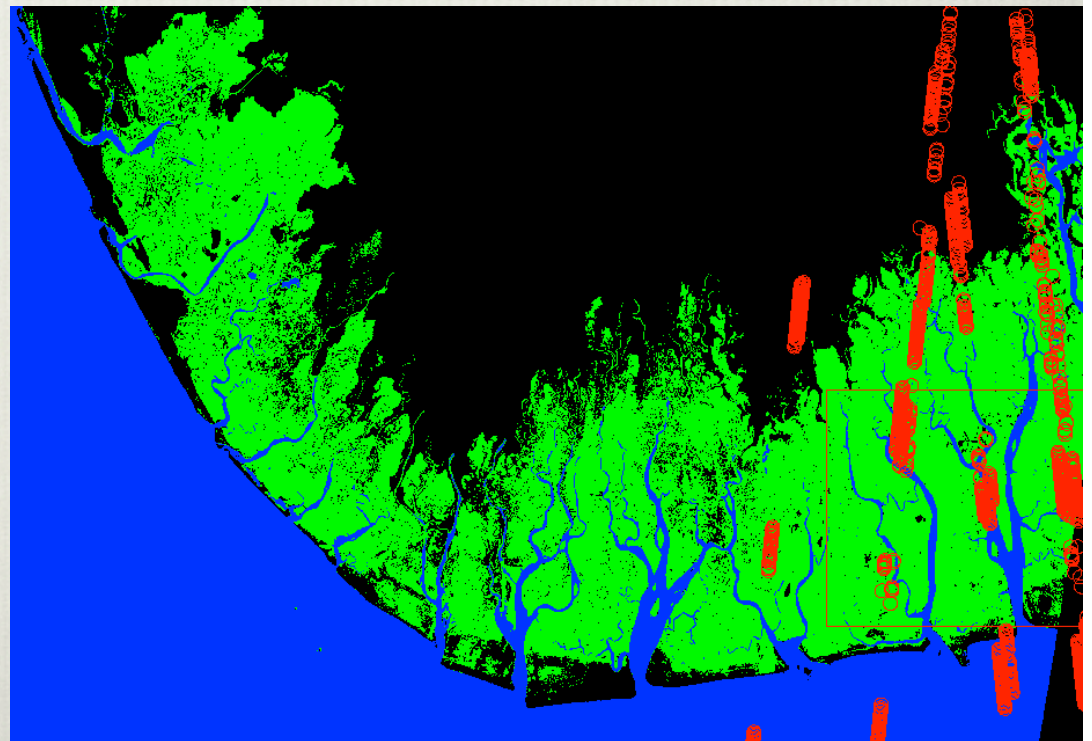
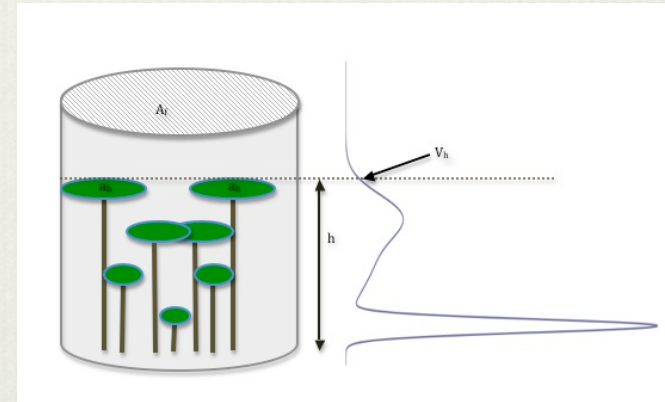


IceSat GLAS

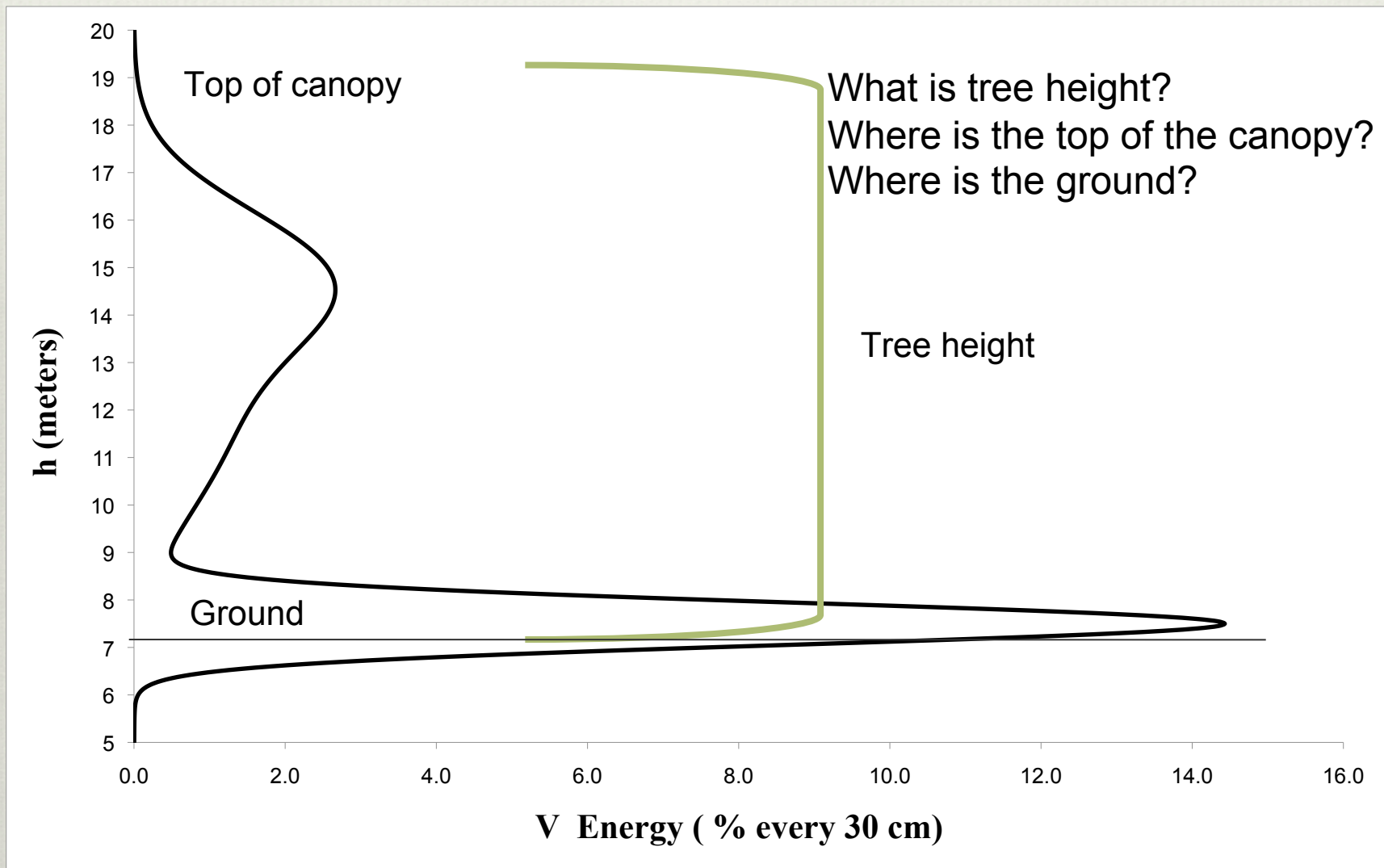


Icesat GLAS

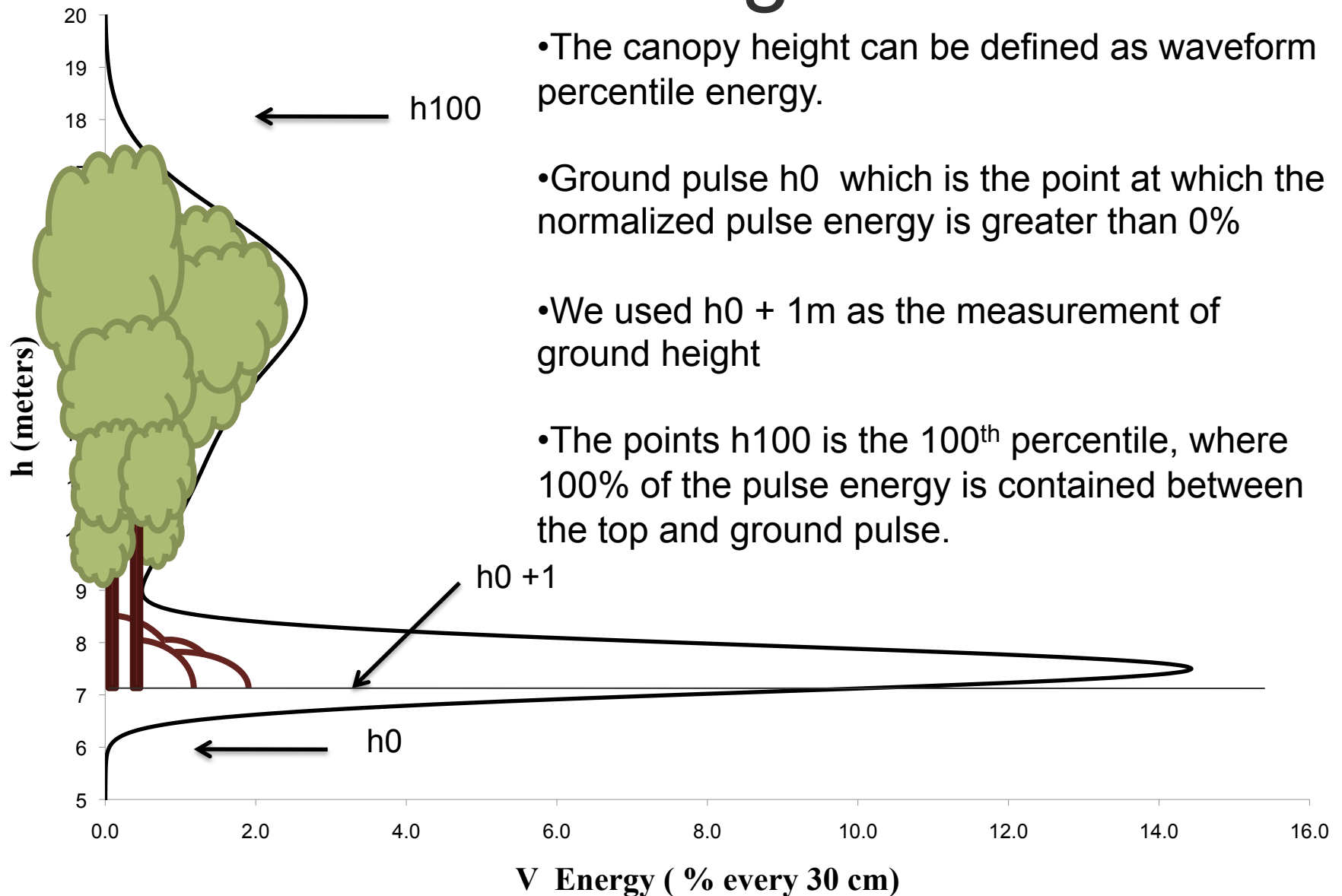
- ❖ Measures surface elevation along a ground track for 33 days every 4 months
- ❖ Best alternative for global canopy height calibration
- ❖ Lidar advantage over field data is geolocation accuracy, high sampling density, 3-D geometry of the canopy
- ❖ Footprint size of 60-70 m, sampling every 170 m
- ❖ GLAS 14 level-2 data : Global Land Surface Altimetry Data Product
 - ❖ Senegal, Gambia, Guinea Bissau, Guinea, Nigeria, Cameroon, Mozambique, Tanzania and Madagascar



- Used data from cloud free profiles
- Excluded waveforms with data unsuitable for determining tree height



Tree height



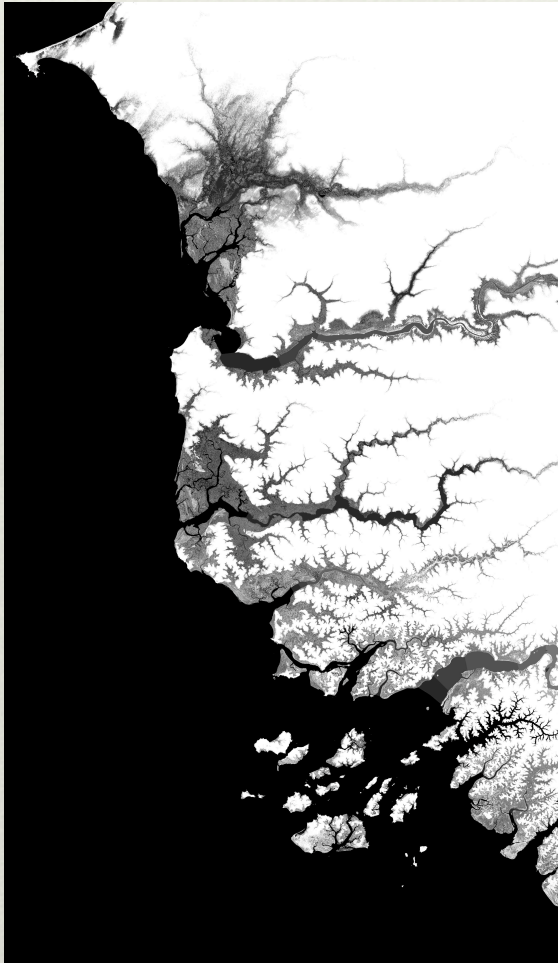
Shuttle Radar Topography Mission



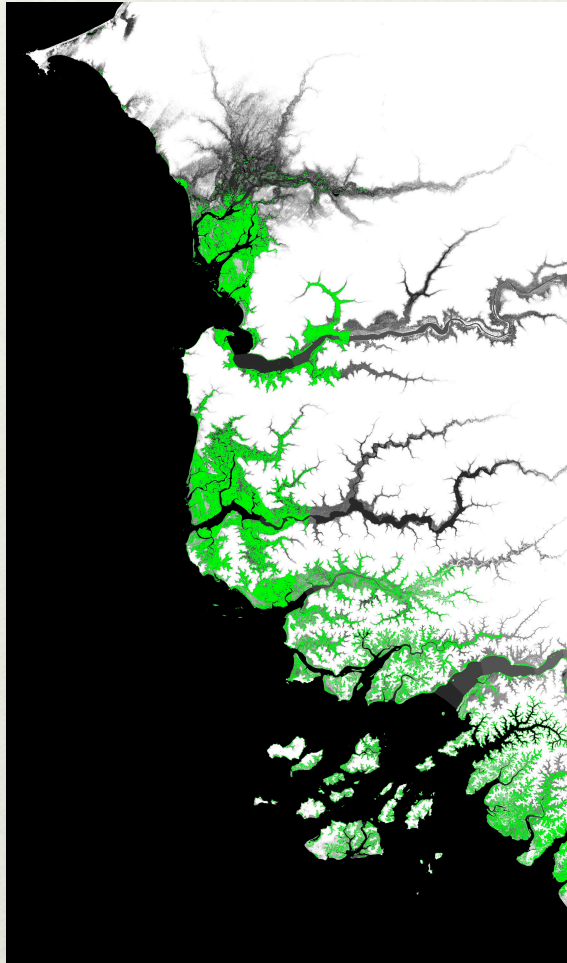
Space shuttle Endeavor and 60m long SRTM antenna (from USGS)

- ❖ February 11-22, 2000
- ❖ Covered over 80% of earth's land surface
- ❖ Spaceborne Imaging Radar C (SIR-C) and X-band Synthetic Aperture Radar (X-SAR)
- ❖ 30 m resolution over the US and 90 m resolution for the rest of the World

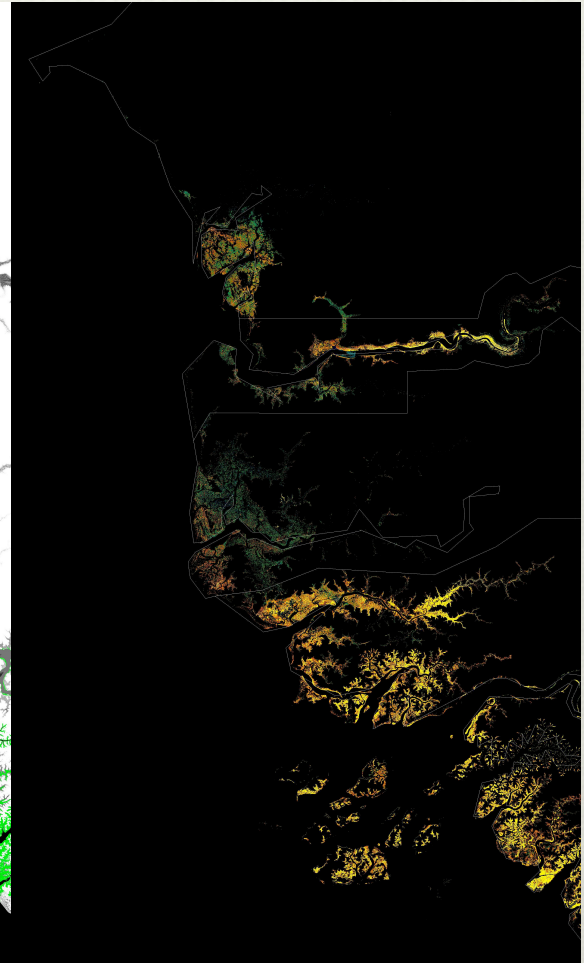
SRTM height calibration



DEM

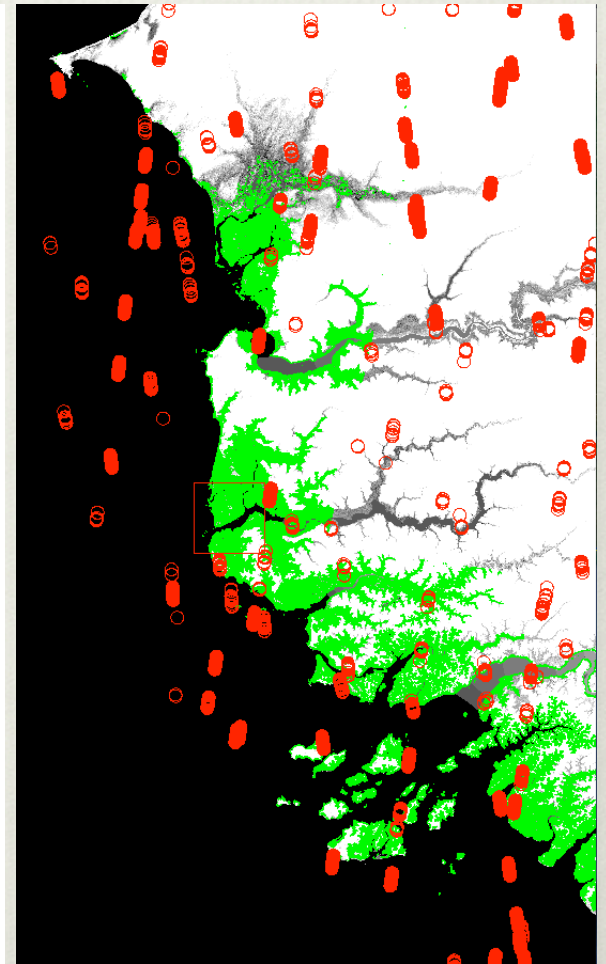
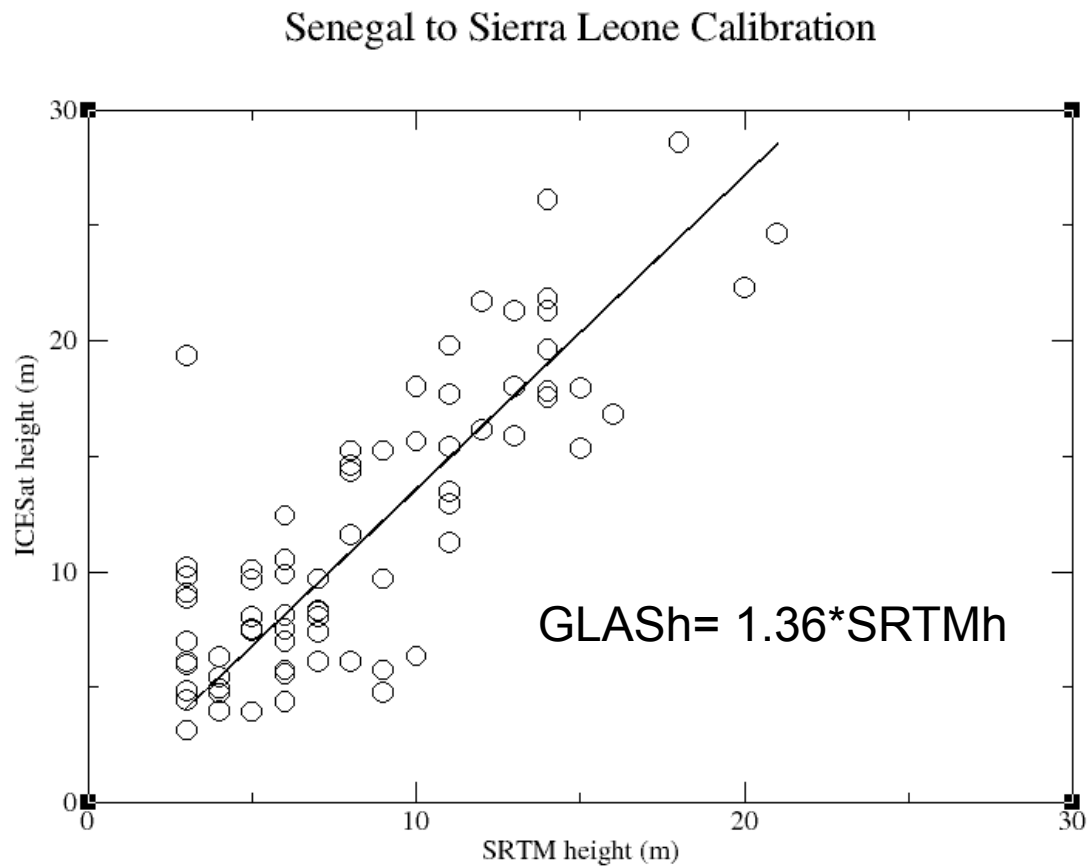


DEM + landcover

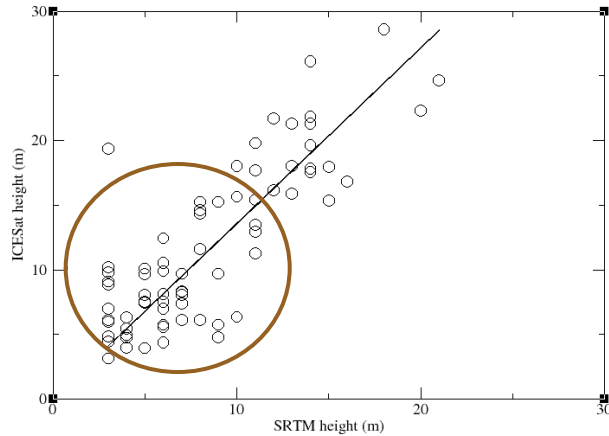


Mangrove DEM

SRTM height calibration



Senegal to Sierra Leone Calibration



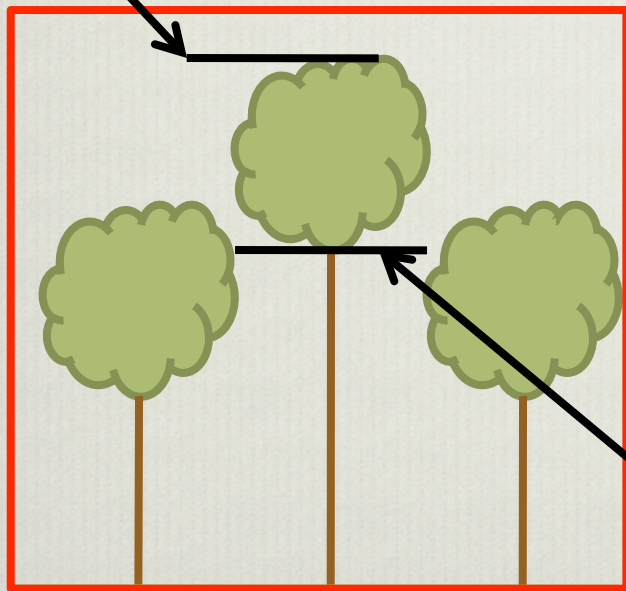
❖ Error: combination of measurement error and natural variability

❖ SRTM: phase unwrapping, radar speckle, volume decorrelation, system noise

❖ IceSat: Geolocation error, higher sensitivity to center of footprint

❖ Natural variability in size and density

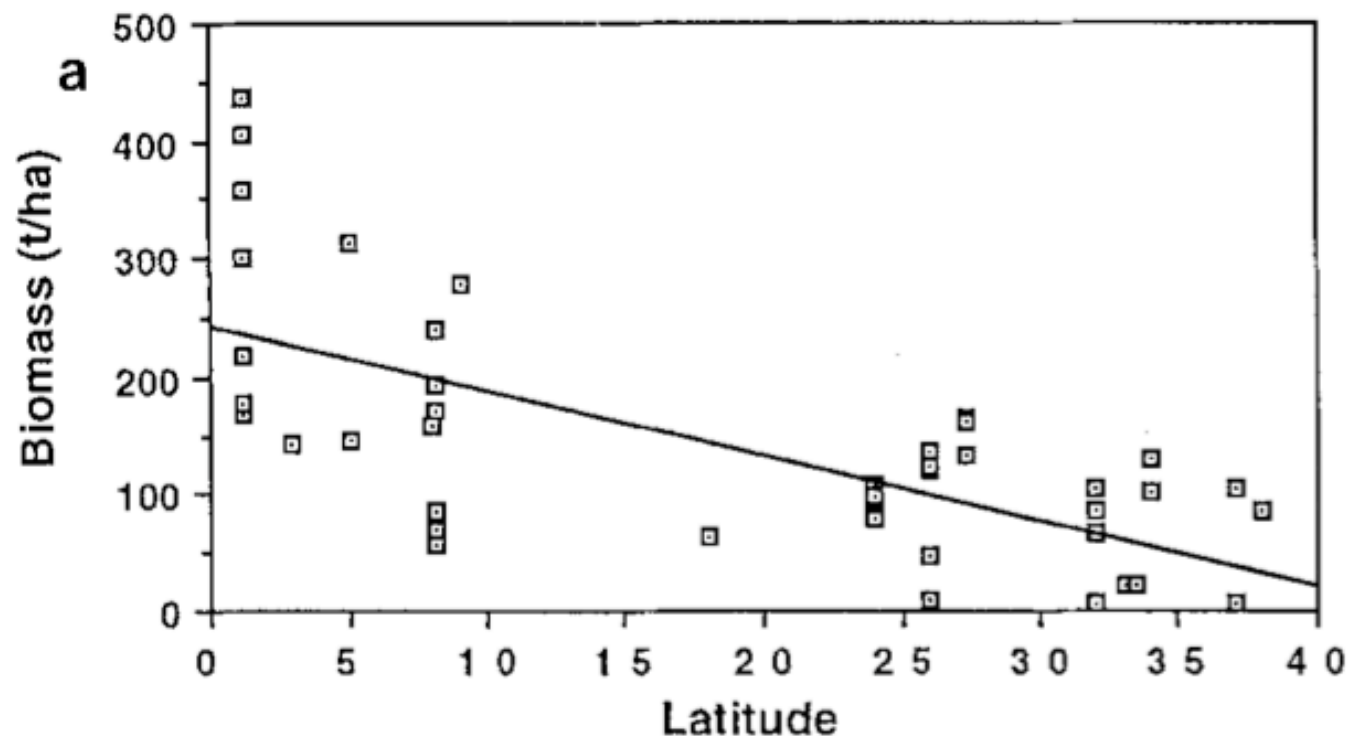
GLAS height



SRTM height

SRTM biomass calibration

Biomass (Mg) = 10.48 *height + 34.99 20% error



Saenger and Snedaker, 1993

Results

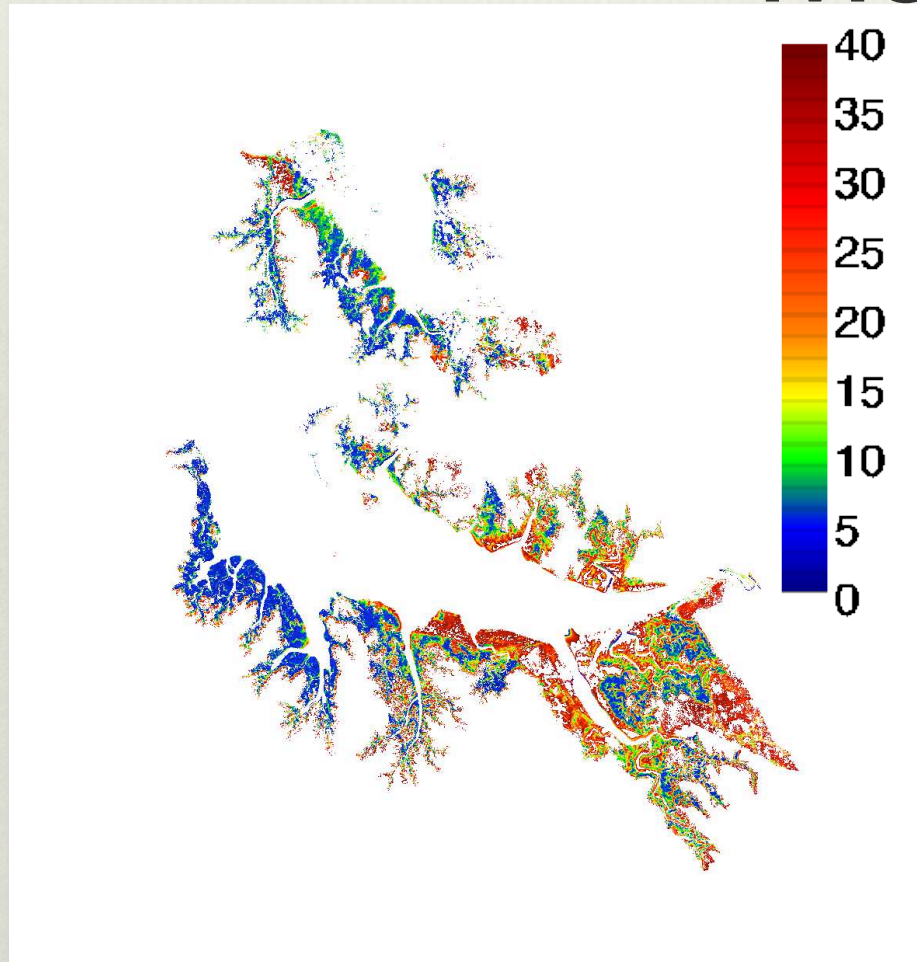
Results: Landcover map

Country	Area in km2	Previous area estimate	Alternate estimate
Angola	154	607	1,250
Benin	18	17	69
Cameroon	1,483	2,434	
Congo	15	188	120
Cote d'Ivoire	32	644	150
Djibouti	17	10	NA
DRC	183	374	226
Egypt	1	861	NA
Equatorial Guinea	181	277	257
Eritrea	49	581	NA
Gabon	1,457	1,759	2,500
Ghana	76	241	100
Guinea	1,889	3,083	2,963
Guinea Bissao	2,806	3,649	2,484
Kenya	192	961	530
Liberia	189	427	190
Madagascar	2,059	3,403	3,270
Mauritania	0.4	1	10
Mozambique	3,054	3,459	1,000
Nigeria	8,573	11,134	10,515
Senegal	1,200	1,830	1,853
Sierra Leone	955	1,695	1,838
Somalia	30	910	NA
Soudan	4	937	NA
South Africa	12	353	11
Tanzania	809	2,456	1,155
Togo	2	NA	26
AFRICA	25,442	42,291	30,517

Height calibration equations

Country	Unweighted linear fit	Weighted linear fit	Calibration curve	Random Error (rms)	Systematic error (slope difference)
Angola	1.17	1.19	$h=1.18 \cdot \text{SRTMheight}$	4.62	0.01
Cameroon	1.17	1.19	$h=1.18 \cdot \text{SRTMheight}$	4.62	0.01
Congo	1.17	1.19	$h=1.18 \cdot \text{SRTMheight}$	4.62	0.01
Cote d'Ivoire	1.36	1.36	$h=1.36 \cdot \text{SRTMheight}$	4.62	0
Democratic Republic of Congo	1.17	1.19	$h=1.18 \cdot \text{SRTMheight}$	4.62	0.01
Djibouti	1.15	1.17	$h=1.16 \cdot \text{SRTMheight}$	3.8	0.01
Egypt	1.15	1.17	$h=1.16 \cdot \text{SRTMheight}$	3.8	0.01
Equatorial Guinea	1.17	1.19	$h=1.18 \cdot \text{SRTMheight}$	4.62	0.01
Eritrea	1.15	1.17	$h=1.16 \cdot \text{SRTMheight}$	3.8	0.01
Gabon	1.17	1.19	$h=1.18 \cdot \text{SRTMheight}$	4.62	0.01
Gambia	1.36	1.36	$h=1.36 \cdot \text{SRTMheight}$	3.7	0
Ghana	1.36	1.36	$h=1.36 \cdot \text{SRTMheight}$	3.7	0
Guinee	1.36	1.36	$h=1.36 \cdot \text{SRTMheight}$	3.7	0
Guinee Bissao	1.36	1.36	$h=1.36 \cdot \text{SRTMheight}$	3.7	0
Kenya	1.15	1.17	$h=1.16 \cdot \text{SRTMheight}$	3.8	0.01
Liberia	1.36	1.36	$h=1.36 \cdot \text{SRTMheight}$	3.7	0
Madagascar	0.985		$h=0.985 \cdot \text{SRTMheight}$	1.9	
Mauritania	1.36	1.36	$h=1.36 \cdot \text{SRTMheight}$	3.7	0
Mozambique	1.17	1.17	$h=1.17 \cdot \text{SRTMheight}$	3.3	0
Nigeria	1.2	1.2	$h=1.20 \cdot \text{SRTMheight}$	2.96	0
Republic of Benin	1.2	1.2	$h=1.20 \cdot \text{SRTMheight}$	2.96	0
Senegal	1.36	1.36	$h=1.36 \cdot \text{SRTMheight}$	3.7	0
Sierra Leone	1.36	1.36	$h=1.36 \cdot \text{SRTMheight}$	3.7	0
Somalia	1.15	1.17	$h=1.16 \cdot \text{SRTMheight}$	3.8	0.01

Height and biomass Map

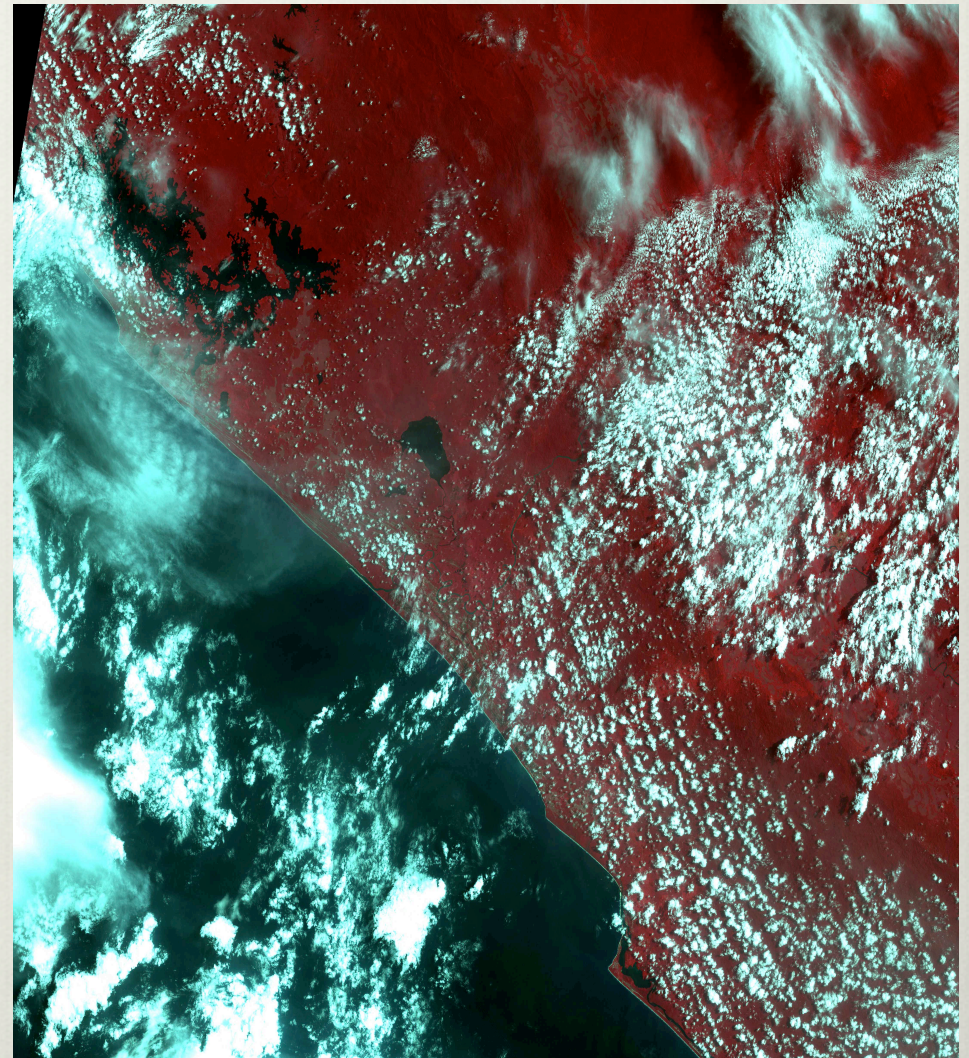


Gabon height map

Country	Mean height in m	Total biomass in Mg	Biomass in Mg/ha
Angola	7.6	2,226,915	144
Benin	3.9	171,326	95
Cameroon	16.3	14,393,930	97
Congo	17.05	122,583	81
Cote d'Ivoire	10.73	595,186	186
Djibouti	4.5	179,667	103
DRC	7.24	2,554,017	140
Egypt	6.1	8,849	124
Equatorial Guinea	12.3	3,719,552	205
Eritrea	5.15	550,347	112
Gabon	14.09	35,230,691	242
Ghana	7.56	7,607,178	147
Guinea	7.92	28,104,993	149
Guinea Bissao	9.4	47,291,626	168
Kenya	6.33	2,455,214	127
Liberia	8.96	3,069,580	163
Madagascar	8.53	31,888,567	155
Mauritania	5.1	4,862	111
Mozambique	7.33	43,007,973	141
Nigeria	8.35	132,242,206	154
Senegal	5.06	13,286,938	111
Sierra Leone	9.03	15,619,508	164
Somalia	2.98	248,894	83
Soudan	3.34	35,235	88
South Africa	9.81	208,514	174
Tanzania	11.77	16,181,258	200
Togo	4.67	21518.064	105
AFRICA	9	401,027,126	158

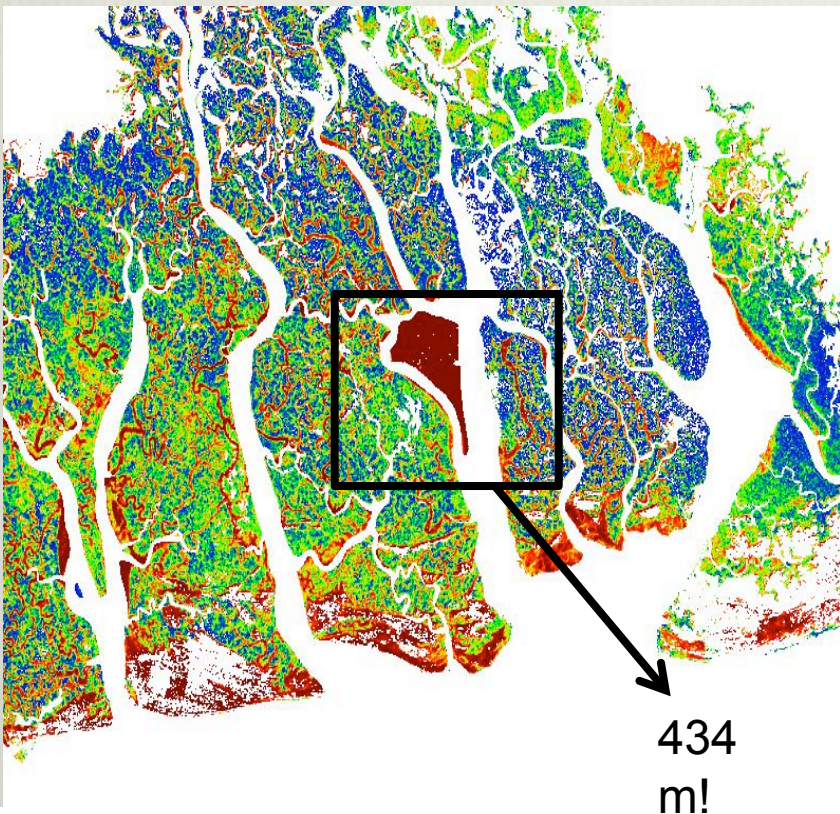
Sources of Error

- ❖ Clouds in the Landcover Maps
- ❖ Difficulty of differentiating between mangrove forests and rainforests in Central Africa

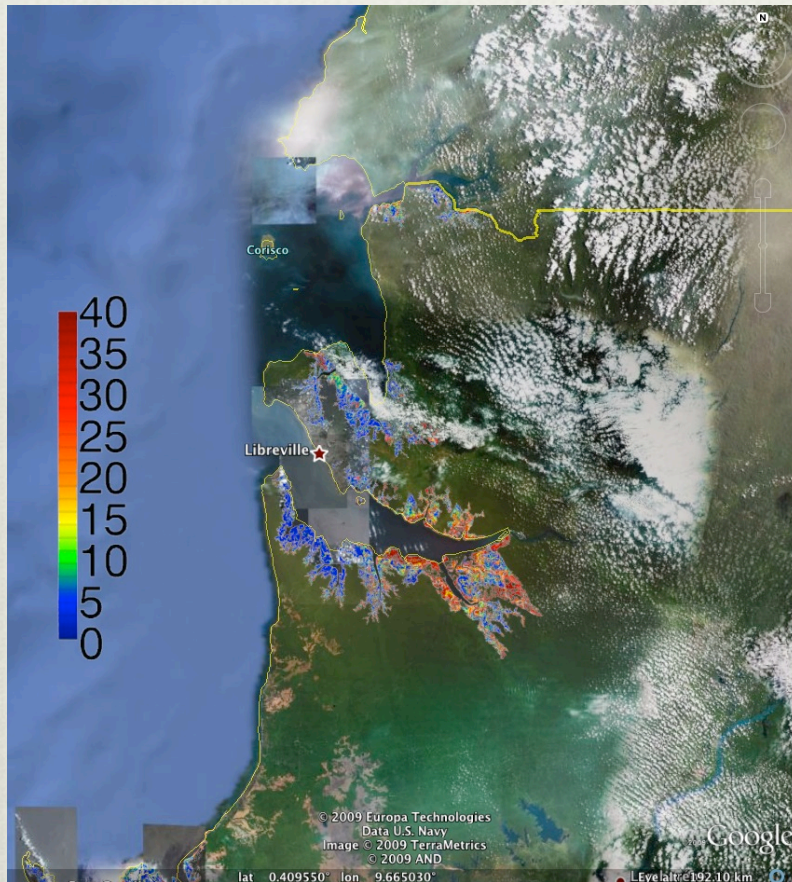


Sources of Error

- ❖ In SRTM we witnessed several areas with very high height measurements
 - ❖ Primarily on islands and were due to unwrapping
 - ❖ Error in height measurements



Google Earth



- ❖ Converted the height maps into .kmz
- ❖ Will be available for download from our website

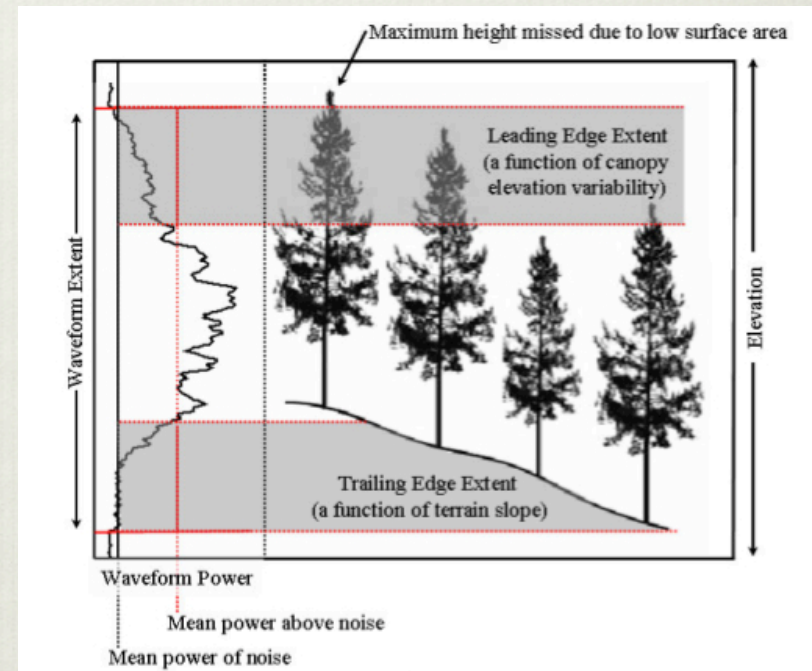
Conclusions

Conclusions from maps

- ❖ Largest areas of mangrove:
 - ❖ 1) Nigeria 2) Mozambique 3) Guinea Bissau
 - ❖ 4) Madagascar 5) Guinea
- ❖ Tallest trees:
 - ❖ 1) Congo (17m) 2) Cameroon (16m) 3) Gabon (14m) 4) Tanzania (12m) 5) Cote d'Ivoire (11m)
- ❖ Largest total biomass:
 - ❖ 1) Nigeria 2) Guinea Bissau 3) Mozambique 4) Gabon 5) Madagascar
- ❖ Highest Biomass per ha (Mg/ha):
 - ❖ 1) Gabon (242 Mg/ha) 2) Equatorial Guinea (205 Mg/ha) 3) Tanzania 4) Cote d'Ivoire 5) South Africa

GLAS and SRTM

- ❖ The combination of GLAS and SRTM data for height measurements works well for vegetation measurements in areas without ground topography or areas in which ground topography is known
- ❖ How do we correct for ground topography and the impact of slope?
 - ❖ DEM and shape of waveform
 - ❖ Examples of equations by Lefsky et al (2007) based on the shape of waveform



Future work

- ❖ 3-D structure of mangroves in the Caribbean
- ❖ SRTM-X band data
- ❖ Expand to Coastal and Rainforests



Thank you!

